



Review

Heavy metal loss from agricultural watershed to aquatic system: A scientometrics review



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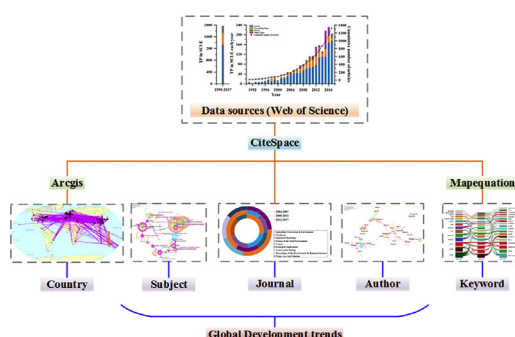
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HIGHLIGHTS

- The watershed-scale migration mechanisms of heavy metal loss were reviewed.
- Network maps were constructed to illustrate salient patterns and emerging trends.
- Relationships among cited authors, journals and keywords were explained visually.
- The complex environmental impacts of heavy metals will continue to be focused on.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 28 February 2018

Received in revised form 29 April 2018

Accepted 29 April 2018

Available online 8 May 2018

Editor: D. Barcelo

Keywords:

Heavy metal

CiteSpace

Agricultural system

Aquatic environment

Diffuse pollution

China

ABSTRACT

Heavy metal pollution in soil and aquatic environments has attracted widespread attention due to its persistence, accumulation in the food chain and negative effects on ecological and human health. However, analyses of the watershed-scale migration mechanisms of heavy metal loss from agricultural systems to aquatic systems have seldom been studied systematically. Therefore, this review summarizes the available data in the literature (2003–2017) using CiteSpace software to provide insights into the specific characteristics of heavy metal loss from agricultural watersheds to aquatic systems and consequently shows global development trends that scientists can use for establishing future research directions. As opposed to traditional review articles by experts, this study provides a new method for quantitatively visualizing information about the development of this field over the past decade. The results indicate that among all countries, China was the most active contributor with the most publications and cooperated the most with other countries. In addition, most articles were classified as environmental sciences and ecology, environmental sciences or agricultural studies. Furthermore, based on a keyword co-word analysis by CiteSpace, it was concluded that erosion-linked transport of heavy metals was the most influencing factor of mitigation mechanism. Additionally, the migration characteristics of heavy metals in farmland soils and water under the complex environment impacts of various factors such as climate change and land-use changes were of great significance that future studies should focus on.

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1. Introduction

Along with rapid urbanization, industrialization and agricultural intensification, fertilizers and pesticides have been widely used in modern agriculture to safeguard crop yields and quality (Bao et al., 2012; Caliskan et al., 2008; Kumar and Jha, 2015). However, the excessive application of these agricultural inputs can result in residues that stay in farmland soil or are transported with rainfall or irrigation water to aquatic ecosystems, and these inputs have become a worldwide concern and a challenging environmental issue due to their serious risks to the human body and water quality (Schoumans et al., 2014; Grillo et al., 2014). On the one hand, increased pollutants such as heavy metals in farmland soils can directly accumulate in crops and may lead to damage and the alteration of animal or human physiological functions through direct ingestion, dermal contact and food intake (Lai et al., 2010). On the other hand, diffuse agricultural pollutants such as nitrogen (N) and phosphorus (P) that are derived from fertilizers can cause water quality deterioration. Therefore, the primary role of watershed management and protection is to protect human health while protecting ecological security and promoting more coordinated economic and environmental development.

To develop sustainable agricultural and effective watershed water management strategies, an assessment of the diffuse pollutants lost from agricultural systems to the aquatic systems in the watershed is important. Scientists have already conducted numerous studies on the sources, cycling and distribution of nitrogen and phosphorus within agricultural systems and on the global effects of watershed nutrient loss from agricultural sources to rivers, estuaries, marine waters and lakes (Pieterse et al., 2003; Sharpley et al., 1999; Ulén et al., 2007; Ma et al., 2016; Zhang et al., 2017). Recently, except for nutrients, heavy metal pollution has attracted widespread attention in terms of both soil and aquatic environments due to its persistence, the accumulation of heavy metals in the food chain and the negative effects of heavy metal pollution on ecological and human health (Lin et al., 2016; Wei and Yang, 2010; Zhang et al., 2016; Ji et al., 2017). Once heavy metals are transferred into an aquatic system, they may inhibit normal aquatic activities, and most heavy metals pose serious threats to the public who use the water from those systems as a source of drinking water or for recreation (Ghreif et al., 2012; Jiao et al., 2014).

Agriculture is a pathway for diffuse heavy metal pollution to travel from farmland soil to surface water (Jiao et al., 2015). Soil heavy metal contents are affected by two main factors, the natural background levels and anthropogenic inputs of heavy metals (Nan et al., 2002; Zhang, 2006). The natural concentrations of heavy metals in farmland soils

depend on the composition of the geological parent materials (Rattan et al., 2005; Shan et al., 2013). Anthropogenic inputs result from the use of not only chemical fertilizers but also pesticides and irrigation with polluted water (Cai et al., 2012; Lee et al., 2006; Lu et al., 2012). To identify mechanisms to effectively reduce heavy metal concentrations, many scientists in many countries have conducted studies on heavy metal pollution, including sources of pollution, estimated pollution, and pollution control and management, which provide valuable information. Jiao et al. (2015) identified the impacts of land-use conversions on diffuse heavy metal pollution at the watershed scale and characterized soil erosion processes for effective diffuse heavy metal control. Gu et al. (2014) suggested that in the farmland soils of the Pearl River Estuary, Cd, Cr, and Cu were mainly controlled by chemical fertilizers, and Ni was primarily impacted by wastewater discharges from electroplating factories. In addition, Shan et al. (2013) reported that in comparison with paddy lands, soils in dry lands had greater accumulations of all heavy metals, which can be explained by a higher rate of phosphorus fertilizer application and a longer farming history. Although much attention has been given to heavy metal pollution both in farmland soils and aquatic environments, the mechanism of migration and the transportation process have rarely been studied systematically. Moreover, no previous review mapped out the linkage or working relationships among the clusters of researchers and their countries in this field. Also, no previous studies have analyzed its research corpus to such depth to include aspects such as co-citation clusters, keywords, or research clusters. To bridge these gaps in extant literature by undertaking an in-depth scientometric review of the global on the sustainability we used CiteSpace software to conduct a visual scientometrics analysis. The most obvious advantage of CiteSpace is that it allows scholars to investigate the specific research areas by analyzing the citations, co-citations, geographical distribution, thus drawing very useful conclusion (García-Lillo et al., 2016; Yu and Shi, 2015). So far, it has been widely used in research trend detection, author cooperative analysis, development of journal, development of the whole subject field and so on (Merigó and Yang, 2017; Wang and Xu, 2016).

The purpose of this study is to comprehensively and systematically provide a scientometrics review of the research on heavy metal loss from agricultural systems to aquatic systems at a watershed scale. More specifically, our analysis mainly focuses on the network of cooperation among countries, co-authorship and co-occurring keywords resulting from CiteSpace, which is a visualization tool that analyzes references obtained from the Web of Science Core Collection (WoSCC). Therefore, the knowledge domains, quantified research patterns, intellectual structure and emerging trends in this field can be explored,

which are helpful for obtaining more accurate and complete information and offering insights into research topics and trend evaluation over time from different perspectives. The method and result of this article may serve for future research as an alternative demonstration of research advancements.

2. Data acquisition and methods

2.1. Data collection and processing

The paper retrieval source for the analysis is the Web of Science Core Collection (WoSCC): Science Citation Index Expanded (SCI-E), which is maintained by Clarivate Analytics (Chen et al., 2014). The search terms included the following: TS (Topic Search) = (farmland* AND water* AND (“trace metal*” OR “heavy metal*” OR “trace element*” OR “cadmium” OR “Cd” OR “copper” OR “Cu” OR “lead” OR “Pb” OR “zinc” OR “Zn” OR “nickel” OR “Ni” OR “mercury” OR “Hg” OR “arsenic” OR “As” OR “Chromium” OR “Cr”)). This database is regarded as the most important and most frequently used scientific database in most fields. The whole records including titles, abstracts, and cited references were then exported to CiteSpace for subsequent analysis. Based on the frequency of studies about watershed heavy metal loss from agricultural systems to aquatic systems over the past two decades, this study systematically reviews a large number of studies between 2003 and 2017.

2.2. Scientometrics analysis methods

CiteSpace is a Java-based scientific visualization software package used for analyzing and visualizing co-citation networks developed by Dr. Chaomei Chen (2006). CiteSpace provides various functions for facilitating the understanding and interpretation of network patterns, including identifying the major topic areas, finding hotspots and automatically labeling clusters with terms from selected literature. In CiteSpace, contributing authors, countries and journals were mapped. This can help identify and visualize major contributing factors for the evolution of the hospitality knowledge map. Hot research topics and frontline research in the hospitality field were identified based on frequency of popular key words used in journal articles. In viewing the maps, a node represents one item such as a keyword, journal, or reference. In addition, the links describe the co-citation or co-occurrence between these nodes (Xie, 2015). Furthermore, each node is depicted with a series of tree rings in different colors, where blue indicates the oldest and orange indicates the newest. CiteSpace also makes it easier to identify pivotal points by recognizing the nodes with high betweenness centrality (Freeman, 2008). Pivotal points are highlighted with a purple ring in order to stand out in a visualized network. The betweenness

centrality is defined in the following Eq. (1).

$$Centrality(node_i) = \sum_{i \neq j \neq k} \frac{\rho_{jk}(i)}{\rho_{ik}} \quad (1)$$

In the Eq. (1), ρ_{jk} represents the number of shortest paths between node j and node k , and $\rho_{jk}(i)$ is the number of those paths that pass through node i . At the document level, the importance of each document in a co-citing network can be partially evaluated by the indicator betweenness centrality (Li et al., 2017).

In this study, most of the analysis can be performed by CiteSpace, such as scientific outputs, subject categories, journals and so on. However, scientific publication has a spatial component, such as the locations of authors. The analysis of this spatial component through geographic information retrieval methods may offer more insight into the research pattern and trends across spatial scale. Therefore, we introduced ArcGIS into the field for the retrieval and discovery of geographic information and employed Map equation to visualize the cooperation networks among countries.

3. Results and discussion

3.1. Characteristics of publication outputs

Fig. 1 shows that the total publications (TP) of all types in the SCI-E increased from 1 in 1990 to 204 in 2017, and the TP of published articles increased from 1 to 176. A total of 1317 publications related to watershed heavy metal loss from agricultural systems to aquatic systems were identified between 1990 and 2017, and they were categorized into 12 document types (article, proceeding paper, meeting abstract, review, editorial material, letter, news item, note, correction, book chapter, addition, and reprint). In addition, articles are the dominant document publication type (comprising 70% of the total publications), followed by proceedings, reviews and other types of publications. An ascent curve describes the cumulative annual number of articles from 1990 to 2017. The cumulative number of articles published in 2017 (1317) was approximately twice that in 2012 (644) and approximately eight times that in 2003. Therefore, the analysis time span of this study was selected as from 2003 to 2017 with a divided 5-year research period.

3.2. Countries co-operation analysis

An analysis of country information based on the affiliations of authors is conducive to understanding the distribution of countries conducting studies on watershed heavy metal losses. As shown in Fig. 2, the study time was divided into three phases (2003–2007, 2008–2012 and 2013–2017), the affiliations of the authors were

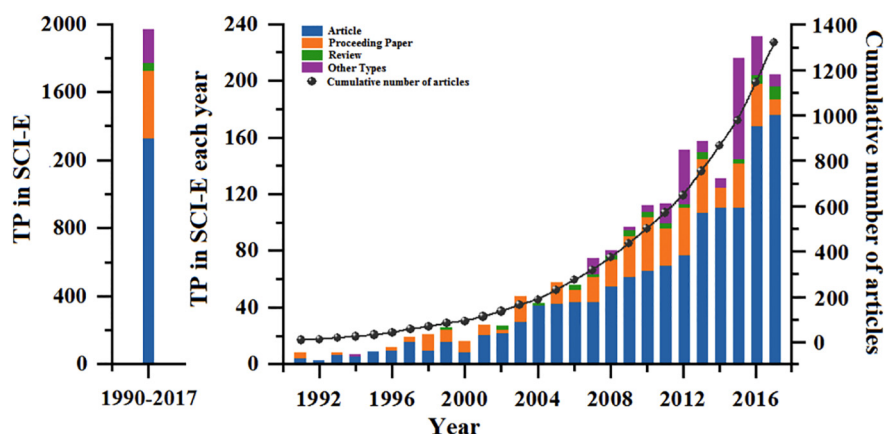


Fig. 1. Publication output performance during 1990–2017.

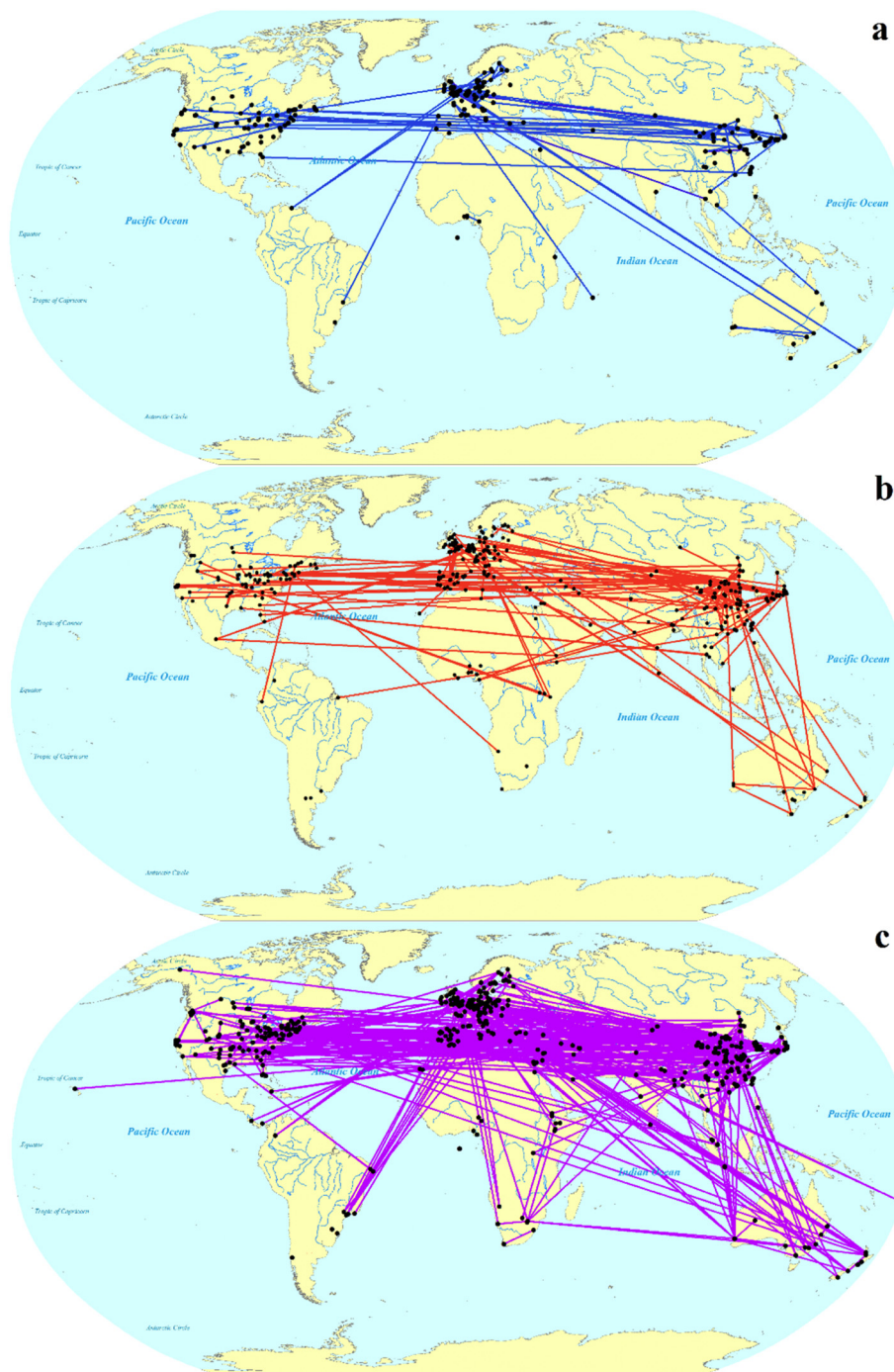


Fig. 2. Global geographic distributions of cooperation among countries during (a) 2003–2007, (b) 2008–2012 and (c) 2013–2017.

mapped across the world using black dots, and the collaborative relationships between institutions were linked by blue lines for 2003–2007 (Fig. 2a), red lines for 2008–2012 (Fig. 2b) and purple lines for 2013–2017 (Fig. 2c). Most institutions and research regions are located in Asia (such as China, Japan and India), North America (such as the USA and Canada) and Europe (such as Germany, France and Spain). Furthermore, as the years get closer to the present, the lines between those three regions (Asia, North America and Europe) become denser, which indicates that closer cooperation was mainly concentrated in Asia, North America and Europe. Additionally, closer cooperation showed that diffuse heavy metal pollution at the watershed scale is still one of the most important environmental problems worldwide and will continue to be a challenge in the near future.

To obtain more information about the countries, the productive countries are shown in detail in Fig. 3. The size and color of the nodes are in proportion to the publication numbers, while the thickness of the connecting lines demonstrates the intensity of cooperation among the countries. The thicker connecting lines indicate a more frequently cooperative relationship between two countries. As shown in Fig. 3, China had the largest number of publications, followed by USA, England and Germany. Obviously, China played a significant and core role in the cooperation network and had the closest cooperation with the most countries, especially with England, Germany and USA. However, Fig. 3 also revealed the lack of collaboration between many countries. Therefore, there were also additional needs to enhance international academic influence with more publications and stronger collaborations.

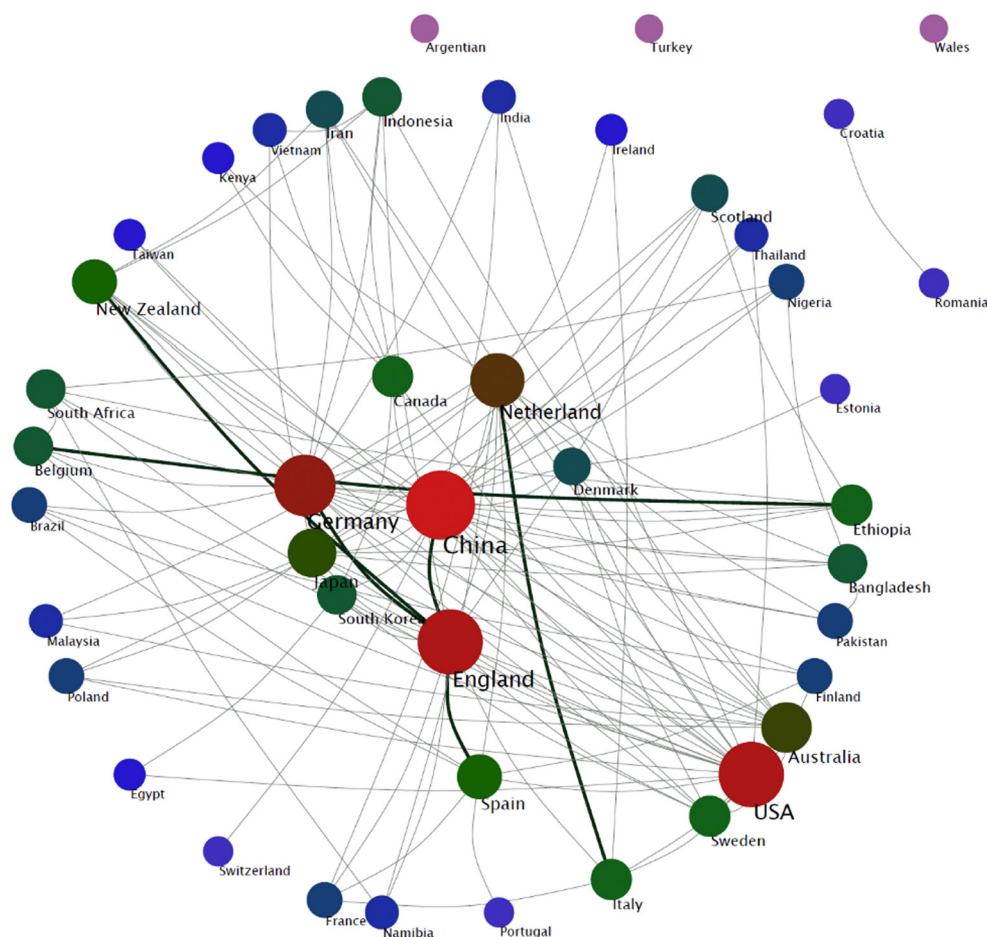


Fig. 3. The cooperation network of productive countries.

3.3. Subject categories co-occurrence analysis

Based on the co-occurrence analysis of subject category, the disciplines involved in watershed heavy metal loss related to a certain knowledge domain can be detected. In this study, the 50 most reoccurring subject categories per year were selected for an analysis of category characteristics. The subject category information was extracted from SU field tags of Web of Science database by CiteSpace and then analyzed. Fig. 4 displays the co-occurrence network from 2003 to 2017, where the node represents a subject category while an edge connecting two nodes demonstrates the co-occurrence of the two subject categories. From Fig. 4, we can observe that environment sciences and ecology (599), environment sciences (507) and agricultural (313) are the top three popular categories of research, followed by water resources (251) and ecology (170). Based on the circle color analysis, the earliest research mainly involved environmental sciences and ecology and environmental sciences, where there are central blue circles. Furthermore, we know that some nodes, as shown by the purple rings, indicate the high centrality values of the corresponding categories. The top 10 productive subjects are shown in detail in Fig. 5. Fig. 5 conveys some interesting and important information on the most frequent subject categories. Of the top 10 subject categories, engineering had the highest centrality and played an important role in watershed diffuse heavy metal pollution. Agriculture was second, followed by ecology and geology. Therefore, watershed heavy metal loss research is a multifaceted and multidisciplinary field that covers a wide range of interests, from environmental science to engineering, geology, agriculture, etc. Above all, “environment science and ecology” and “environment sciences” were the two major subject categories.

3.4. Journal co-citation analysis

Studies on heavy metal loss in agricultural watersheds are disseminated across 255 journals. Table 1 presents the top 10 most frequently cited journals in this field. The top-ranked journal by citation count was Agriculture, Ecosystems & Environment, with 425 records, followed by Science of the Total Environment. Obviously, these two journals were the main sources of cited works for diffuse heavy metal pollution scientists. Undoubtedly, at the Impact Factor (IF) level, Science and Nature had the highest IF (37.205 and 40.137) and a profound influence on related research. To obtain more information about article evolution in journals, we constructed a time-varying doughnut. In this process, 5 years were regarded as a time slice (2003–2007, 2008–2012 and 2013–2017), and the top 5 journals in each slice were selected for further analysis.

Fig. 6 depicts a simplified picture of the most highly cited journals. It can be seen that Agriculture, Ecosystems & Environment occupied an important position over the past 15 years, which is also consistent with the results in Table 1. Geoderma, Catena and the Journal of Hydrology also contributed to the research in this field and had stabilizing influences over the past decade. In addition, it is worth noting that 2013–2017 witnessed a prosperous development of agricultural watershed heavy metal loss research in Science of the Total Environment. Therefore, the research in this field attracted more attention over time.

3.5. Author co-citation analysis

The period from 2003 to 2017 with a time slice of 1 year was chosen for the co-authorship analysis, and the selection criterion was the top

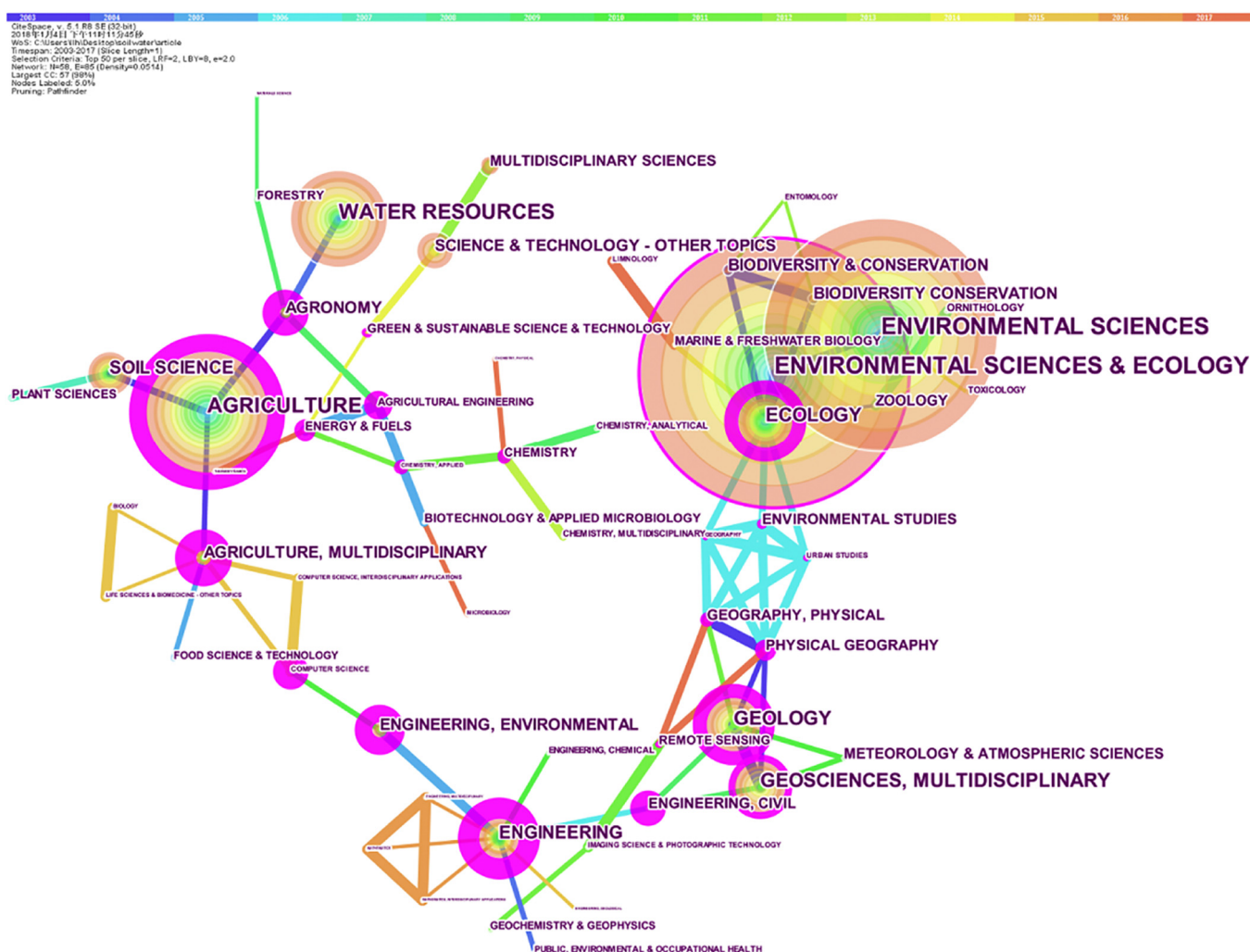


Fig. 4. Subject category network during 2003–2017.

50% per slice. Then, a collaboration network for the productive authors was generated. The collaboration map is presented in Fig. 7. The size of the circles represents the amount of publications of the authors, and the links between two circles suggest a collaboration between individual authors. It is worth noting that many authors tended to cooperate

with a relatively stable group of the collaborators, each of which usually had two or more core authors. It is evident that these top productivity authors have made great achievement on this research field. Of these authors, FH. Hao, Y. Li and XY. Zhang produced the largest number (10) of articles in this field and Y. Li received the highest rate of citations

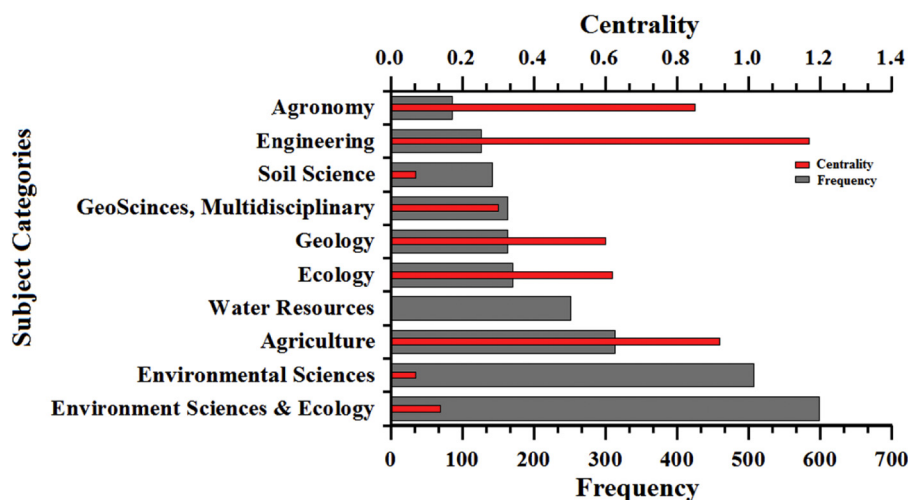


Fig. 5. Top 10 subjects in terms of frequency and centrality.

Table 1
Top 10 journals in terms of frequency and IF in 2016.

Frequency	Journal	IF 2016
425	Agriculture, Ecosystems & Environment	4.099
321	Science of the Total Environment	4.900
319	Journal of Hydrology	3.483
262	Science	37.205
248	Soil Science Society of America Journal	1.844
247	Journal of Environmental Quality	2.344
217	Nature	40.137
202	Environmental Pollution	5.099
185	Journal of Environmental Management	4.010
168	Agricultural Water Management	2.848

IF: impact factor.

(27). The major clusters with a core author shown in Fig. 7 represent the most representative research groups in this field that offer highly individualized scientific research information to other researchers. Among

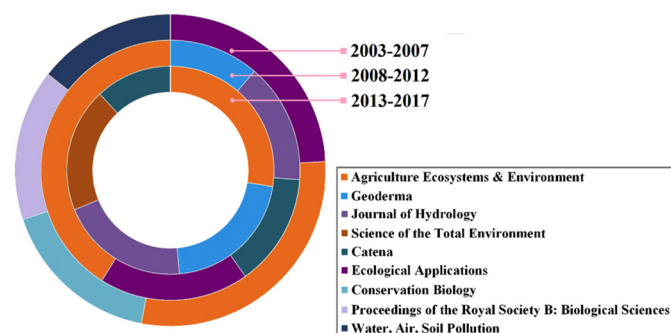


Fig. 6. The co-citation of journals with centrality.

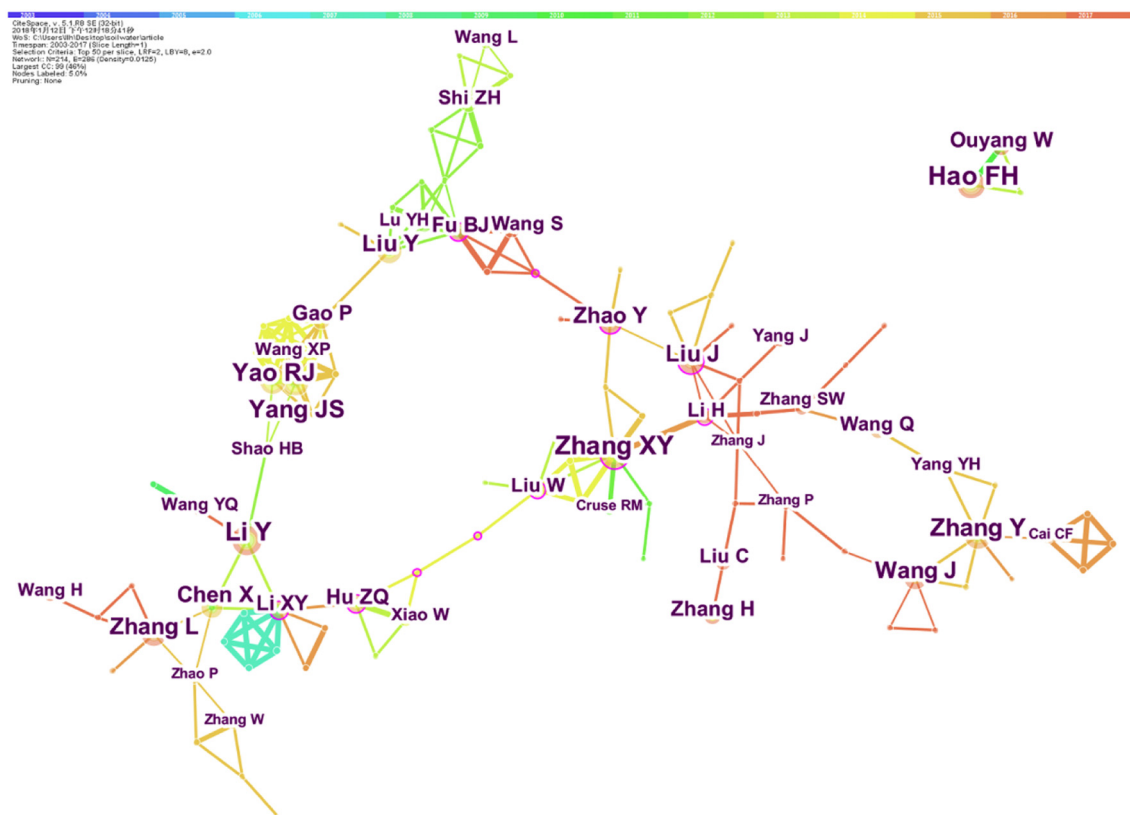


Fig. 7. The cooperation network of productive authors.

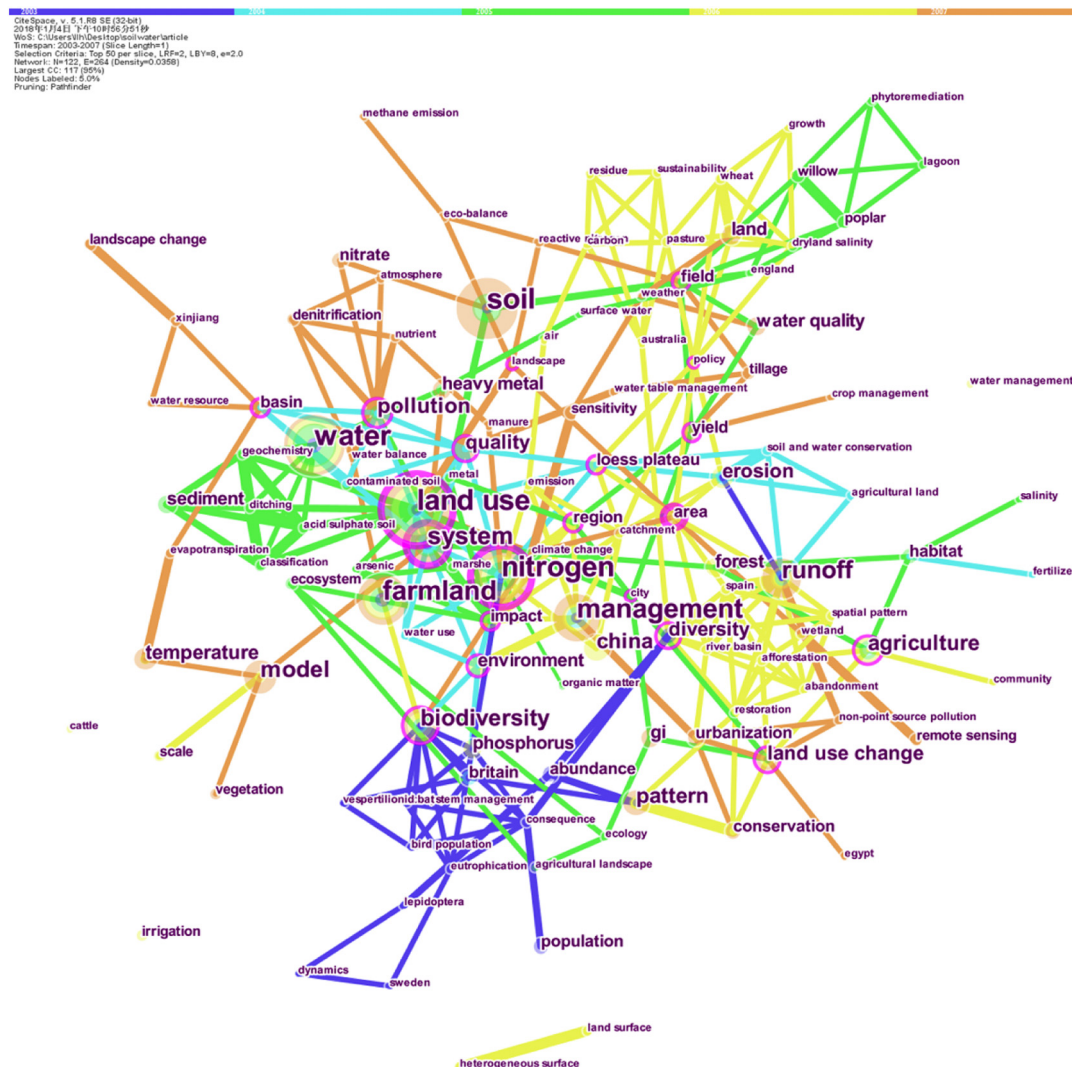
the top 20 authors, the achievements of Chinese authors in this field are the highest in the world, which reflect China's emphasis on this field.

3.6. Keyword co-word analysis

Keywords can be regarded as the soul of an article, and a keyword co-word analysis can be used for detecting research topics, analyzing research hotspots as well as for monitoring the research frontier transitions of a certain knowledge domain (Baskerville, 1904; Yu et al., 2017). The keyword co-word analysis related to agricultural watershed heavy metal loss was conducted by CiteSpace. During this process, keywords with the same meaning were combined, such as "contamination" and "pollution". We selected the top 50 items every 5 years and developed three co-word networks for the analysis. As shown in Figs. 8, 9 and 10, the three stages of research nodes increased gradually, and the cross fusion of each cluster was significantly enhanced. These results showed that the relevant studies of heavy metal loss from agricultural watersheds to aquatic systems were constantly expanded and developed. Table 2 shows the top 15 keywords in terms of frequency and centrality in the field of watershed heavy metal loss from agricultural systems to aquatic systems over the past 15 years. The following is a common analysis based on both tables and figures. The selection of the discussed keywords was generally based on the frequency and centrality.

3.6.1. The period of identifying the pollution characteristics of heavy metals (2003–2007)

Fig. 8 depicts the simple network of the most frequent keywords. Some nodes have purple rings around their outer rims that indicate the high centrality of this field. The node "land use" is the main research content in this period. Different land uses have special hydrological, biological and physicochemical characteristics that alter the occurrence of diffuse pollution events. Long-term land use will influence soil production by inducing significant changes in soil functioning (Citeau et al.,



3.6.2. The transition period mainly based on dynamic, process-oriented diffuse heavy metal pollution (2008–2012)

symbolizes the arrival of a diversified research period. Comparing with the period (2003–2007), “system” maintained a stable position due to the complex research content related to aquatic system, river system, soil system and so on. As the frequency of the node “model” increased significantly, there were attempts to develop a physically-based distributed model for simulating diffuse heavy metal pollution based on previous achievements (Velleux et al., 2008). A two-dimensional depth-average numerical model, which couples the RMA2 and TOXIWASP models, was developed to simulate hydrodynamics and to track the fate of heavy metals (Yang et al., 2009). The hydrodynamic results obtained from the RMA2 model can provide simulated flow fields and water-level information for this water quality model. These developments appeared as a transition from the identification of pollution characteristics to dynamic, process-oriented diffuse heavy metal pollution. As shown in Table 2, the node “water quality” cropped out. It seemed the influence of heavy metal on water quality and aquatic environment has been widely paid attention to. As the centrality of node “Agriculture” increased, during this period, agriculture is considered to be the predominant diffuse pressure in rural areas, although not invariably the most severe (Lam et al., 2010). As heavy metals in soil are tightly bound to soil colloids and organic matter, the diffuse heavy metal pollution occurs mainly in particulate form. Consequently, water erosion can act as an important vector for the movement of heavy metals from agricultural watershed to aquatic system. In addition, some study also

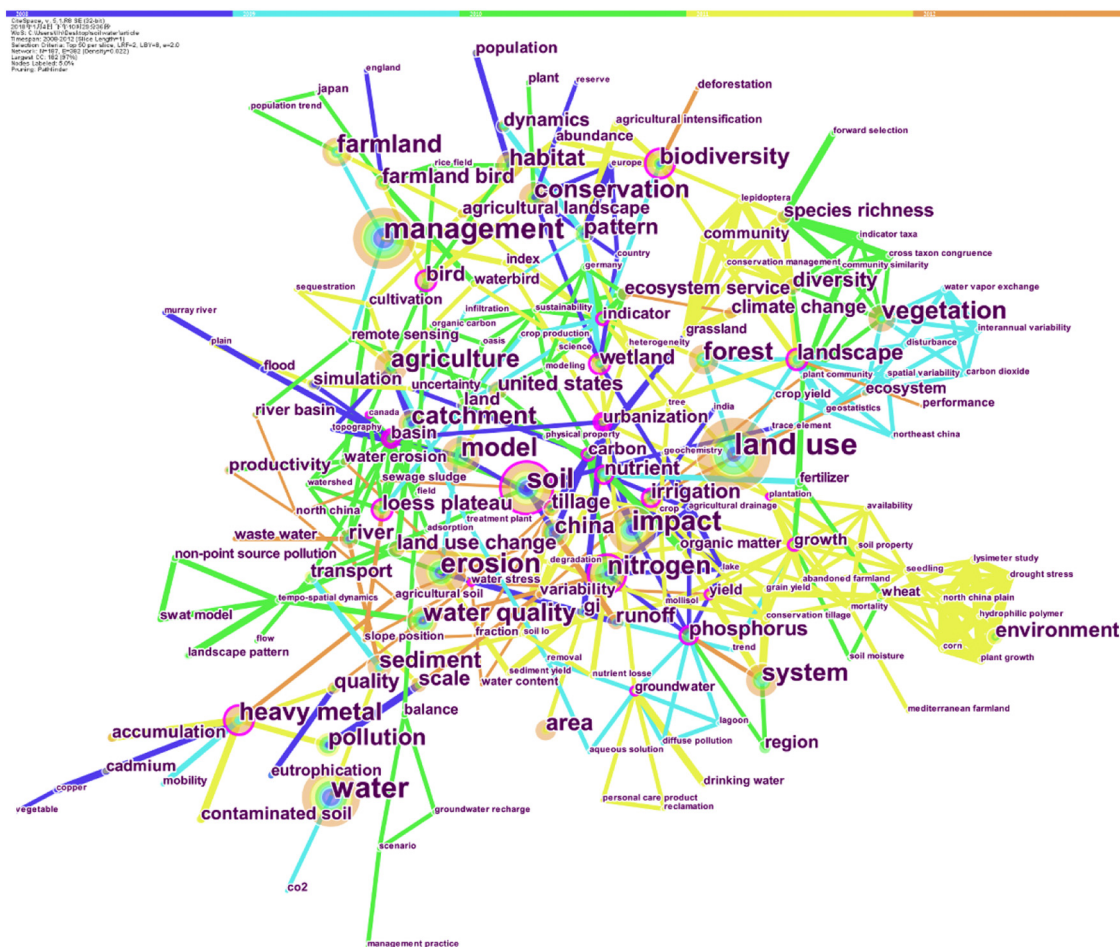


Fig. 9. The network map of watershed heavy metal loss from agricultural systems to aquatic systems during 2008–2012.

showed the fine sediments were the carriers of heavy metals in the surface land, flowing into the aquatic environment by surface runoff.

3.6.3. The period based on the ambient behavior of watershed heavy fractions under complex environmental impacts (2013–2017)

As depicted in Fig. 10, in this period, a higher quantity of research nodes was reached. Obviously, “China” has the highest frequency, followed and linked by “management”, indicating that research on farmland heavy metal pollution and control in China is a popular topic in international research. China's Ministry of Environmental Protection and Ministry of Land and Resources conducted a nationwide survey of soil contaminants and found that the heavy metal concentrations in 19.4% of the agricultural soil samples exceeded the standard limit (MEPPRC and MLRPC, 2014). The arable land per capita in China is less than half of the world average; thus, protecting this precious resource from degradation and contamination has been a high priority in the government's agenda. Moreover, facing the challenges of severe water pollution and resource scarcity, water quality-oriented management and intelligent watershed management were implemented for the water pollution control strategy of the 13th Five Year planning in China (T.J. Zhang et al., 2014; X.L. Zhang et al., 2014). Consequently, over the past 5 years, Chinese scholars have conducted numerous studies focusing on watershed heavy metal loss.

Compared to the period of 2003–2012, the nodes “erosion” and “model” with purple circles showed improved centrality, which indicated the higher value of the keywords. In addition, the nodes linked with “erosion”, such as “runoff”, “simulation”, and “sediment yield” were the main content of the studies. Surface runoff is always accompanied by soil erosion and sediment yield, with the flow carrying soil

materials away. Jiao et al. (2015) reported that the spatial trend of particulate heavy metal (Pb, Cu, Cr and Ni) losses was very similar to that of soil loss, indicating that sediment yield played a more important role in controlling diffuse heavy metal loadings. Zheng et al. (2016) found that the loss of mercury with soil erosion was associated with organic matter loss. Given the worldwide significance of mass transfer in agricultural environments with erosion processes (Chappell et al., 2016; Wang et al., 2017), more studies should focus on examining the erosion-linked transport of heavy metals, and much more attention should be given to high intensity erosion events in future mitigation strategies. For “model”, the model that coupled SWAT and simplified ECM could be used to analyze the characteristics of heavy metal transfer (T.J. Zhang et al., 2014; X.L. Zhang et al., 2014). However, this model is an estimate of the load and not the transport processes of heavy metals (Ouyang et al., 2017). An option for simulating the transport process of heavy metals to water is coupling field transport observations and vertical sediment cores with a hydrodynamic model. An innovative way to estimate the temporal-spatial variability in heavy metals is to combine SWAT with sediment geochemistry, which establishes correlativity between heavy metals and typical diffuse pollutants simulated by the SWAT model (Jiao et al., 2015).

As the node “climate change” exhibited a higher frequency than ever before, climate change indicated that the influence of climate change on soil and water quality, which has recently become an area of concern (Xia et al., 2015a, 2015b). Heavy rainfall can enhance the leaching effect of heavy metals and aggravate the agricultural diffusion pollution. The transformation and migration patterns of heavy metals in aquatic environments are complex, and the influencing mechanisms of climate change on heavy metals are still unknown (Wu et al., 2017). Therefore,



research domains, the SWAT model and basin, and how the field of land-use change still displays a unique research hotspot in 2013–2017. In addition, surface runoff gradually developed into the field associated with grassland and accumulation. The policies are mainly applied to resources and conservation. These structural changes over the past period reflected scientific co-word patterns to some extent.

3.7. Term co-occurrence network analysis

Keyword co-word analysis can provide detailed information about the field of study and analyze research hotspots, but it may not be adequate for comprehensively analyzing the structure of this field. Therefore, abstract term cluster analysis was conducted. Cluster analysis can group similar objects together and determine clusters that represent related study areas. The cluster size is the number of terms included in each cluster. CiteSpace assigns the cluster ID zero to the largest cluster and

Table 2

Top 15 keywords related to watershed heavy metal loss from agricultural systems to aquatic systems for different periods of 2003 to 2017.

2003–2007			2008–2012			2013–2017		
Keyword	Frequency	Centrality	Keyword	Frequency	Centrality	Keyword	Frequency	Centrality
Land use	18	0.27	Land use	44	0.04	China	95	0.03
Soil	17	0.04	Management	37	0.02	Management	86	0.26
Water	17	0.0	Water	35	0.02	Water	79	0.00
Nitrogen	15	0.25	Soil	31	0.10	Impact	76	0.00
Farmland	14	0.03	Erosion	31	0.03	Land use	74	0.06
Management	13	0.05	Impact	30	0.00	Soil	69	0.00
Runoff	11	0.10	Model	25	0.05	Erosion	53	0.13
System	10	0.39	Nitrogen	23	0.13	Model	50	0.13
Model	9	0.09	System	22	0.05	Heavy metal	50	0.00
Biodiversity	9	0.12	Farmland	21	0.02	Pollution	49	0.06
Pollution	7	0.13	Agriculture	21	0.07	Conservation	49	0.29
Pattern	7	0.04	Water quality	20	0.03	Farmland	45	0.03
Agriculture	7	0.04	Conservation	19	0.07	Land-use change	44	0.20
China	7	0.00	Forest	19	0.03	Climate change	43	0.03
Land-use change	6	0.13	Heavy metal	19	0.13	Runoff	42	0.08

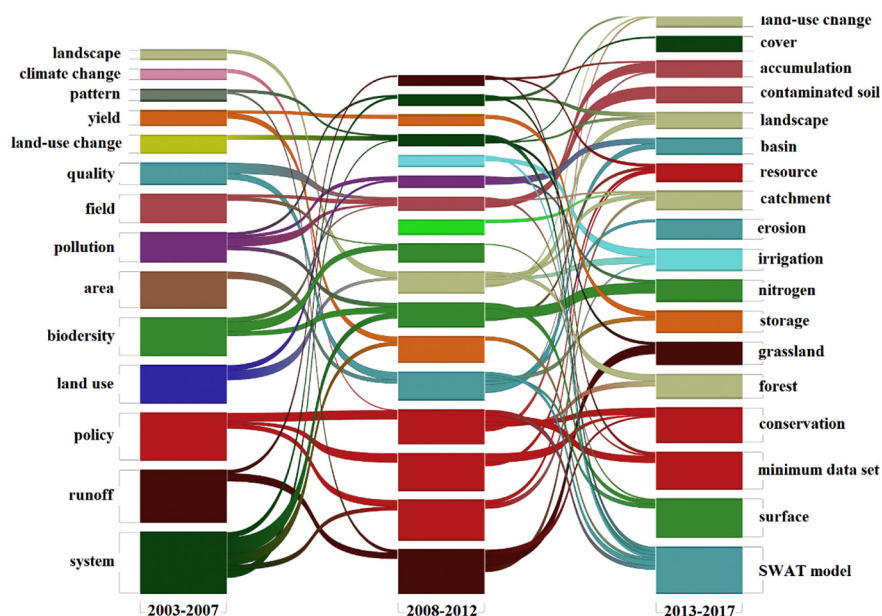
the ID one to the second largest, and so on. As shown in Fig. 12, the five most prominent clusters that were labeled as major research areas on the basis of different terms retrieved from abstract. And it is also necessary to consider other terms from a cluster to further understand the meaning and scope of that cluster. Therefore, Table 3 shows the characteristics of the five prominent clusters. The silhouette silhouette coefficient greater than 0.5 indicates reasonable clustering of data (Kaufman and Rousseeuw, 1990). The silhouette coefficients of all five major clusters exceed 0.9, which shows reasonable clustering results.

Based on Fig. 12 and Table 3 it is obviously that the aim of most literature about watershed heavy metal loss from agricultural systems to aquatic systems focused on ecosystem services. As arable soil provides a variety of ecosystem services that are crucial to food safety water safety and so on ecosystem services that could potentially be provided by heavy metal (HM) contaminated soils would help to achieve soil and water safety not only by improving food security water security but also by helping to protect soil biodiversity and abate global climate change. The ecosystem services provided by HM-contaminated soils should be taken into account in soil and water policy and management systems. In addition although some positive policy results have been achieved over the last decade large uncertainty remains regarding large-scale and long-term policy effects on the sustainability of

conservation planning in agricultural landscapes ecological rehabilitation performance and ecosystem service enhancement.

4. Conclusion

This study offers a comprehensive scientometrics review of heavy metal loss from agricultural watersheds to aquatic systems. In addition, we examined pollution characteristics from multiple perspectives: characteristics of publication outputs, cooperation among countries and authors, and co-occurrence analysis of subject categories and keywords. Over the past 15 years, there were 1317 journal articles related to this field, and the number of articles increased steadily, which indicated that researchers paid increased attention to this field and that the attention was not evenly distributed around the world but was mainly concentrated in North America, Europe and Asia. Meanwhile, international collaborations among North America, Europe and Asia were relatively intimate. Furthermore, China was the most active contributor with the most publications and cooperation among all the countries. In addition, this research is a multifaceted and multidisciplinary field and covers a wide range of interests, from environmental science to engineering, geology, agriculture, etc. Additionally, journals like Agriculture, Ecosystems & Environment and Science of the Total Environment were

**Fig. 11.** The evolution mapping of keyword co-word clusters during 2003–2017.

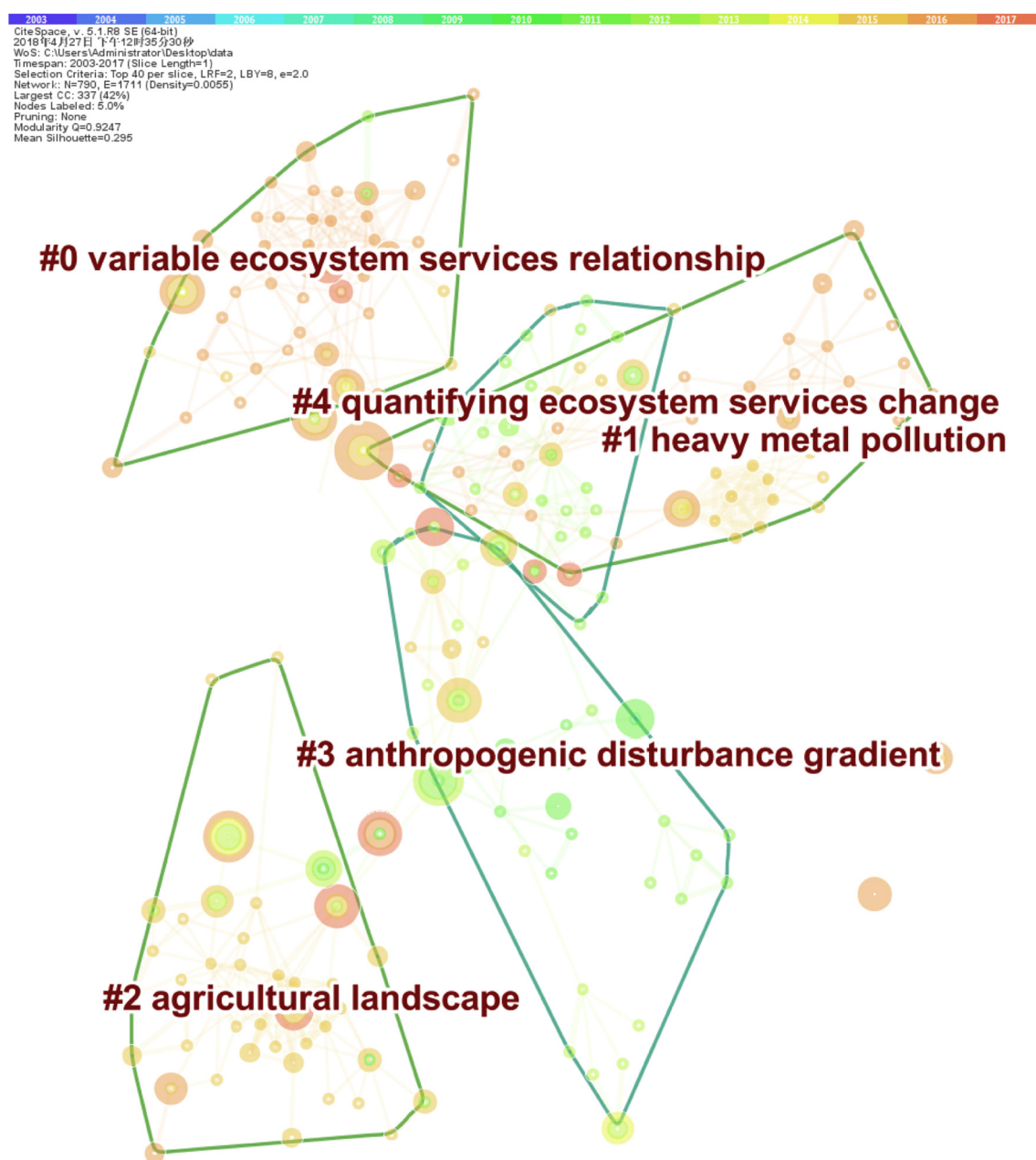


Fig. 12. The term co-occurrence network of watershed heavy metal loss from agricultural systems to aquatic systems during 2013–2017.

the main sources of cited works for diffuse heavy metal pollution scientists. In terms of co-word analysis, we found several interesting keywords with high co-occurrence frequencies. Based on the recent research, erosion-linked transport of heavy metals has been paid much attention for mitigation mechanism. Additionally, the migration characteristics of heavy metals in farmland soils and water under the impact of various factors such as climate change and land-use changes were of great significance that future studies may focus on. Based on

term co-occurrence analyze, most researches aim to enhance ecosystem services thus improve food safety and water safety.

Compared with the traditional reviews from domain experts, the analyses based on CiteSpace in this paper have certain limitations. Some drawbacks existed in CiteSpace, for examples, the first author and corresponding author cannot be distinguished clearly. Some similar co-keywords which should be merged in the same circle have to be combined manually, such as “contamination” and “pollution”, “SWAT

Table 3
Characteristics of clusters.

Cluster ID	Size	Silhouette	Representative terms
0	44	0.946	Variable ecosystem services relationship; ecosystem services value; case study
1	40	0.974	Heavy metal pollution; food safety; arable soil
2	40	0.934	Agricultural landscape; conservation planning; soil biogeochemistry
3	38	0.955	Anthropogenic disturbance gradient; land use type; surface water quality
4	31	0.936	Quantifying ecosystem services change; ecological restoration; policy-driven large scale

model” and “SWAT”. While it is trustworthy that with the sustained efforts of the research group of CiteSpace, this software will overcome these drawbacks and present more accurate and deep knowledge domain in the future. For the method of future study, we will use more indicators to further strengthen the analysis such as using spatial autocorrelation approaches to analyze spatially-dependent characteristics at alternative levels (e.g., state or province). These future directions, as we believe, will further advance both the field of diffuse heavy metal pollution and the study of scientometrics analysis.

Acknowledgments

The research was financially supported by the National Key Research and Development Program of China (2016YFD0800503), the National Natural Science Foundation of China (Grant No. 41622110) and the Fundamental Research Funds for the Central Universities.

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